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Jets and Eruptions in the Transition Region Observed with CDS, EIT and TRACE

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1. Introduction

The Solar and Heliospheric Observatory (SOHO) continues to reveal secrets about the Sun, providing new knowledge about our closest star. The joint ESA and NASA mission is entering its 6th year in space and is one of the most successful scientific mission in the history of space (see NSR Vol 6, No. 4, 1998; Vol 8, No 3, 2000 for details about SOHO and previous results).

2. First glimpse inside a sunspot

Sunspots have fascinated people since Galileo's observations of them contradicted the common belief that heavenly objects were flawless. Sunspots remain mysterious because at first glance, it seems they should rapidly dissipate. Instead, they persist for weeks or more. Why do sunspots last for weeks instead of flying apart? What holds them together?

Using observations from the SOHO/MDI instrument the first glimpse inside sunspots have been presented. MDI explores beneath the surface of the Sun by analysing sound-generated ripples at its surface using a technique called acoustic tomography – a novel method similar to ultrasound diagnostics in medicine that use sound waves to image structures inside the human body.

Previous surface observations had shown that surface material clearly flows out of the spots. The new observations clearly showed that the out-flowing material was just a surface feature and by looking deeper the material is rushing inward, like a planet-sized whirlpool or hurricane. The cool material contracts and sinks at speeds of up to 4000 km per hour and pulls the magnetic fields together.

Another surprise was that sunspots are surprisingly shallow. Conditions in sunspots change from cooler than the surrounding plasma to hotter than the surrounding plasma just 4000 km below the surface.

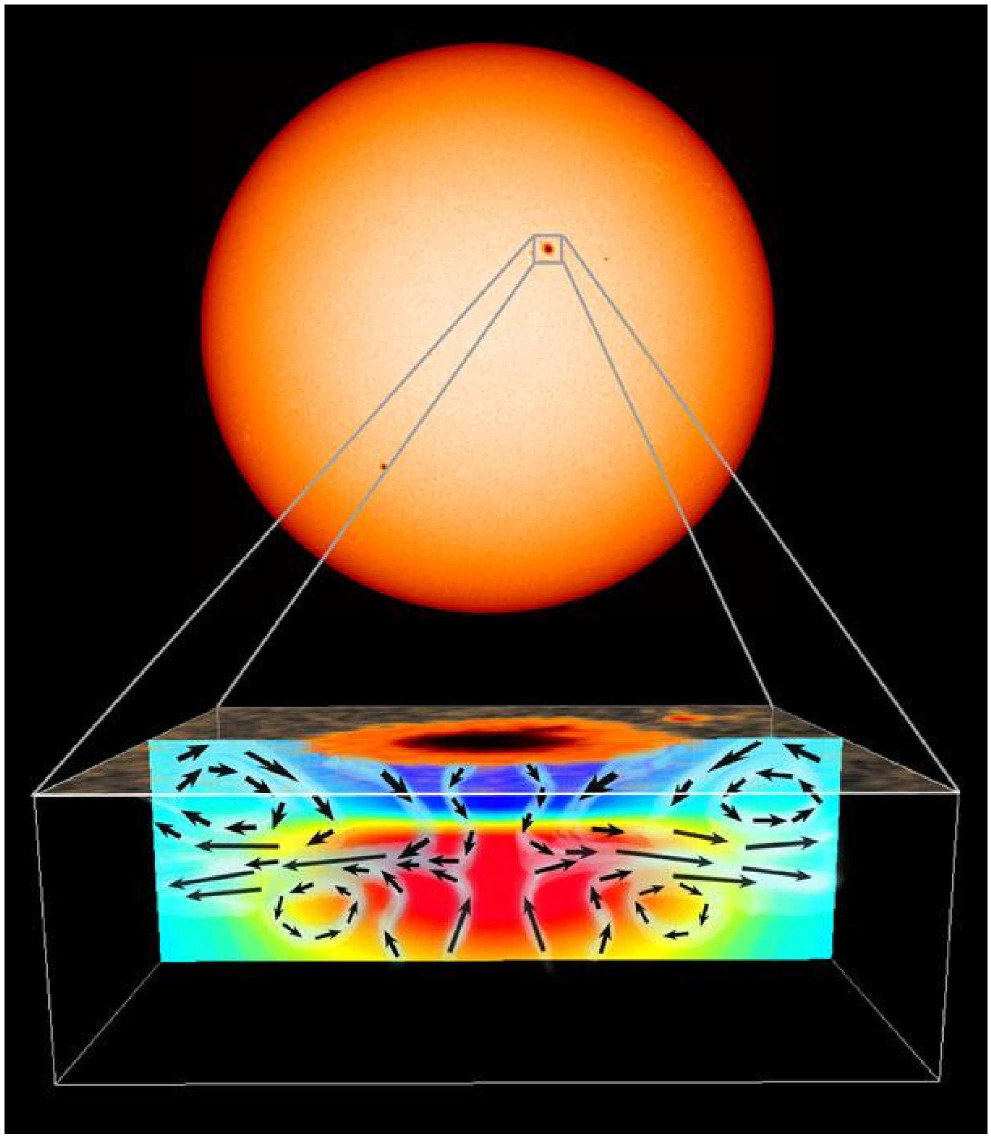

Figure 1. The bottom close-up is a cross section revealing the hidden structure of a sunspot. The plasma flows are represented by the black arrows near the top of the cross-section image, in and around the cool, dark blue region. As long as the magnetic field remains strong, the cooling effect will maintain an inflow that keeps the sunspot stable. This flow will prevent the heat from below to reach the surface, thus the region below the cool area becomes hotter, which is represented by the read area beneath the blue region in the cross section (MDI/SOHO).

3. Active region dynamics

Observations with CDS, SUMER, TRACE and EIT show that the solar plasma at temperatures 0.1 MK to 1.0 MK, trapped inside large magnetic loops in active regions, is extremely dynamic and time variable. TRACE and EIT (at 1-1.5 MK) show emission fronts moving along the magnetic fields, while Doppler shifts of EUV lines observed with CDS and SUMER, reveal that high material velocities in fact occur. Line of sight velocities of -40 to +40 km s^{-1} are typical while velocities approaching 200 km s^{-1} have been detected (see Figure 2).

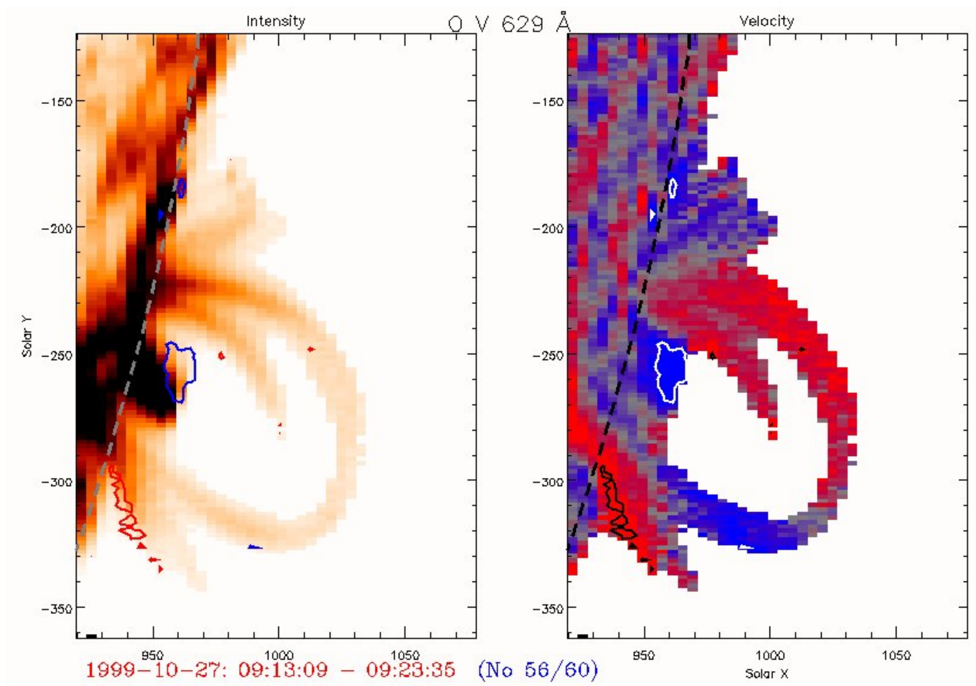

Figure 2. Observing the Sun with a spectrometer like CDS one can derive the intensity and velocity distribution of the plasma in loops. The images show the intensity (left panel) and velocity (right panel) distribution of transition region plasma in an active region on the south-west limb in October 1999. Doppler shifts corresponding to a velocity greater than ± 40 km s^{-1} (144 000 km t^{-1}) are fully red/blue. Contours outline areas with velocities exceeding ± 150 km^{-1} (Courtesy T. Fredvik and O. Kjeldseth-Moe, University of Oslo).

Structures at different temperatures are generally co-located over a wide range of temperatures and they often emit along their full length, thus appearing isothermal. Loops containing coronal temperature plasmas appear to change more slowly. However, this impression may be caused by a large number of (overlapping) loops with changes only in those loops that are magnetically connected to the active transition region loops. The observations point towards a conceptual picture of loops as collections of thin, thermally insulated strands that extend over long sections owing to high thermal conductivity. Heating episodes cause the strands to have different specific temperatures and excite flows and waves causing the observed Doppler shifts.

3-min transition region oscillations above sunspots has been detected from spectral observations with SUMER. Extensive observing programmes of these oscillations in the chromosphere and transition region have been executed by a group in Oslo to investigate these oscillations in more detail. The the observed velocity variations are astounding, providing convincing evidence that the oscillations they observed are upward-propagating, nonlinear acoustic waves.

4. Solar Irradiance and Ultraviolet Spectral Atlases

Due to its influence on the terrestrial atmosphere, the solar irradiance and variability may constitute important sources of climate changes. Variations in the total solar irradiance will directly influence the amount of energy absorbed by land and oceans. Furthermore the EUV spectrum at wavelengths below 1200 Å is the dominant source of energy for heating and ionisation in the terrestrial upper atmosphere at altitudes above 90 km. Any changes in the amount of EUV radiation will therefore change the chemistry, dynamics and temperature of the Earth's atmosphere. A good knowledge of the solar spectral irradiance is thus of critical importance for understanding climate variability and to disentangle natural variations from human made climate changes.

Six independent space-based radiometers since 1978 have been measured the solar irradiance since 1978. The VIRGO instrument on SOHO extends the record of total solar irradiance (TSI) measurements into cycle 23. These observations show that the Sun's output fluctuates during each 11-year sunspot cycle, changing by about 0.1(1980 and 1990) and minima (1987 and 1997) of solar activity. Temporary dips of up to 0.3result of large sunspots passing over the visible hemisphere. It is interesting to note that even if the current solar cycle have been regarded as weaker than the previous cycle (lower sunspot number) the total irradiance is higher than was recorded during the last solar maximum.

A far-ultraviolet and extreme-ultraviolet (FUV, EUV) spectral atlas of the Sun has been derived from observations obtained with the SUMER (Solar Ultraviolet Measurements of Emitted Radiation) spectrograph. The SUMER spectral atlas is the best-ever analysis of the ultraviolet light from the Sun, spanning wavelengths from 670 to 1609 Å (67 to 160.9 nanometres), and identifies some 1100 distinct emission lines, of which more than 150 had not been recorded or identified before SOHO. A spectral atlas is like the Sun's genetic code where the ingredients are chemical elements in all kinds of different ionisation stages, each of them giving clues to what's going on in the Sun's atmosphere. Since the same emission lines can be seen in other stars the new spectral atlas is also of interest for those studying stellar spectra. In addition, a detailed knowledge about the different spectral regions is very important for understanding how the these different wavelengths interacts with the Earth's atmosphere. A close-up of a selected region of the spectral atlas, compared with the irradiance spectrum of Alpha Cen A from HST-STIS, is shown in Fig. 3.

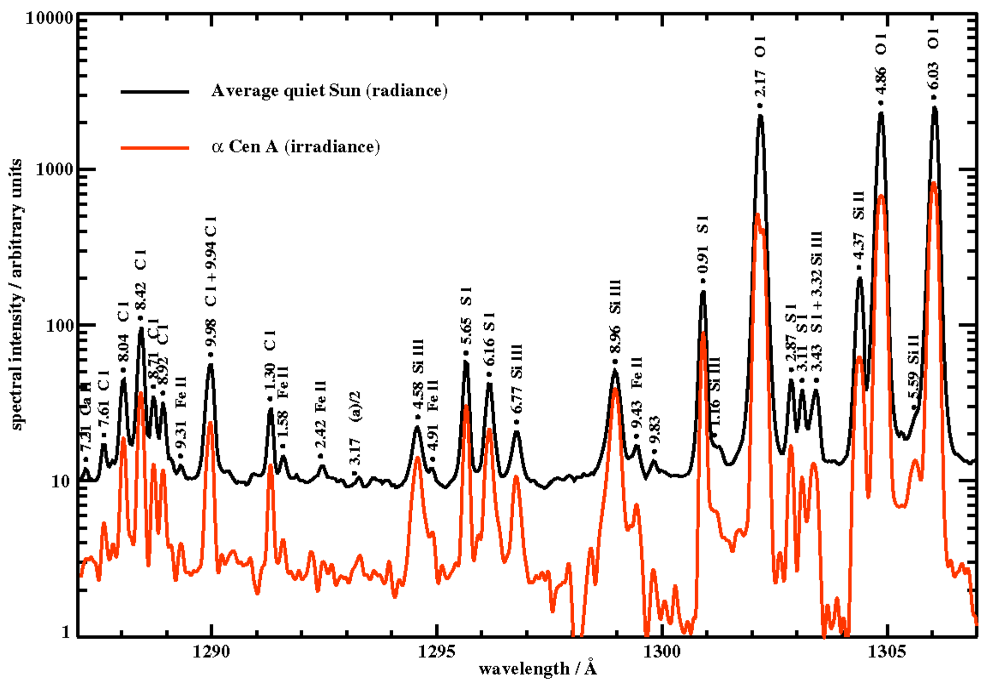

Figure 3. A close-up of a tiny part of the full spectral atlas released from the SUMER instrument, compared with the irradiance spectrum of Alpha Cen A from the STIS instrument on Hubble Space Telescope (SUMER/SOHO).

5. Comets

SOHO is providing new measurements not only about the Sun. The LASCO coronagraph on SOHO has discovered more than 350 comets by September 2001, most of them belonging to sun-grazing comets of the Kreutz family. One particular feature of these observations is the presence of a dust tail for only a few sungrazers while no tail is evident for the majority of them. Analysis of the light curves is used to investigate the properties of the nuclei (size, fragmentation, destruction) and the dust production rates. Due to the availability of near real-time images on the SOHO web site, the majority of SOHO's comet discoveries are made by amateur astronomers!

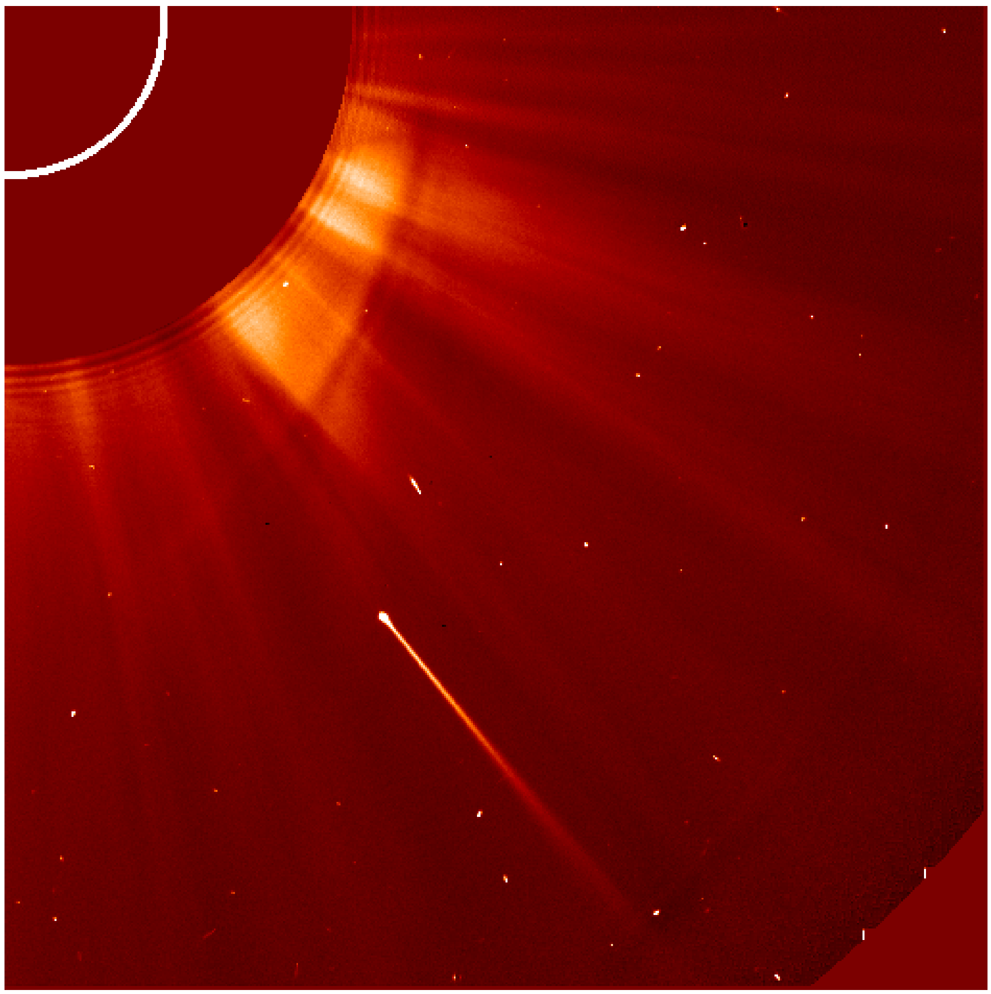

Figure 4. A very bright Sun-grazing comet was discovered by SOHO on Monday, 22 October. Solar radiation heats the comet, causing an outgassing of water molecules and dust. The dust scatters sunlight at visible wavelengths, making the comet bright in LASCO images (LASCO/SOHO).

The break-up of Comet LINEAR was monitored by the SWAN instrument The total amount of water vapour observed by SWAN from 25 May to 12 August 2000 is estimated at 3.3 million tonnes. Only about 1left on 6 August, when observations by the Hubble Space Telescope of the dying comet's fragments gave an estimate of the total volume of the fragments. Combining the two numbers give a remarkably low value for the density - about 15 kg m^{-3}, compared with 917 kg m^{-3} for familiar non-porous ice. Even allowing for an equal amount of dust grains, 30 kg m^{-3} is far less than the 500 kg m^{-3} often assumed by comet scientists. For this reason, the estimated water ice content is expected to raise some controversy. Assuming a homogenous composition of the whole comet, the nucleus had a diameter of about 750 metres at the beginning of SWAN's observation series.

6. Mission Status and Future Plans

Although long past the design lifetime of 2 years, SOHO is doing remarkably well. Fuel reserves of 123 kg should last 10 more years according to conservative estimates, and the solar array degradation is at only 10measures must be applied. The gradual degradation of instruments and multi-layer insulation due to EUV exposure and high-energy particles is as expected, and not a cause of concern. Barring unexpected events, there seems to be no technical reason why SOHO and its instruments should not be able to complete observations of a full solar cycle. With several years until heirs to the throne can be expected, we hope that SOHO will continue its hegemony in the field of solar and heliospheric observations for years to come.

While we have made considerable progress, we have still not realized the full potential of SOHO to explore the diverse parameter space offered by the solar cycle. We have learned many new things about the solar interior, but we do not understand the solar cycle variations of zonal flows and the velocity shear at the base of the convection zone or whether there are g-modes in the deep interior. We have made significant progress in understanding the origin and acceleration of solar wind plasma, but we still need to understand how the spatial distribution of the wind varies over the solar cycle. We still do not know what causes CMEs to erupt, nor how they are accelerated, nor whether the variation in the rate is the same from cycle to cycle. SOHO has revolutionized our ability to predict earthward-directed disturbances by giving up to three days' advance notice. This is of importance since we know that the most geoeffective disturbances occur in the declining phase of the solar cycle. Thus, extending the SOHO mission beyond solarmax has also practical implications on our society since timely warnings can be important to avoid damages to our technology based infrastructure.